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(54) **FILLET OPTIMIZATION FOR TURBINE AIRFOIL**

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F01D 5/18 (2006.01)
F01D 5/20 (2006.01)

(52) **U.S. Cl.**

CPC ***F01D 5/186*** (2013.01); ***F01D 5/20*** (2013.01); *F05D 2220/32* (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC ... F01D 5/18; F01D 5/186; F01D 5/20; F01D 5/288; F01D 5/187

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,589,823 A 5/1986 Koffel
5,403,158 A 4/1995 Auxier

(Continued)

FOREIGN PATENT DOCUMENTS

EP 1 267 041 A2 12/2002
EP 1 270 873 A2 1/2003

(Continued)

OTHER PUBLICATIONS

Extended European Search Report and Opinion issued in connection with corresponding EP Application No. 16200948.4 dated Jul. 3, 2017.

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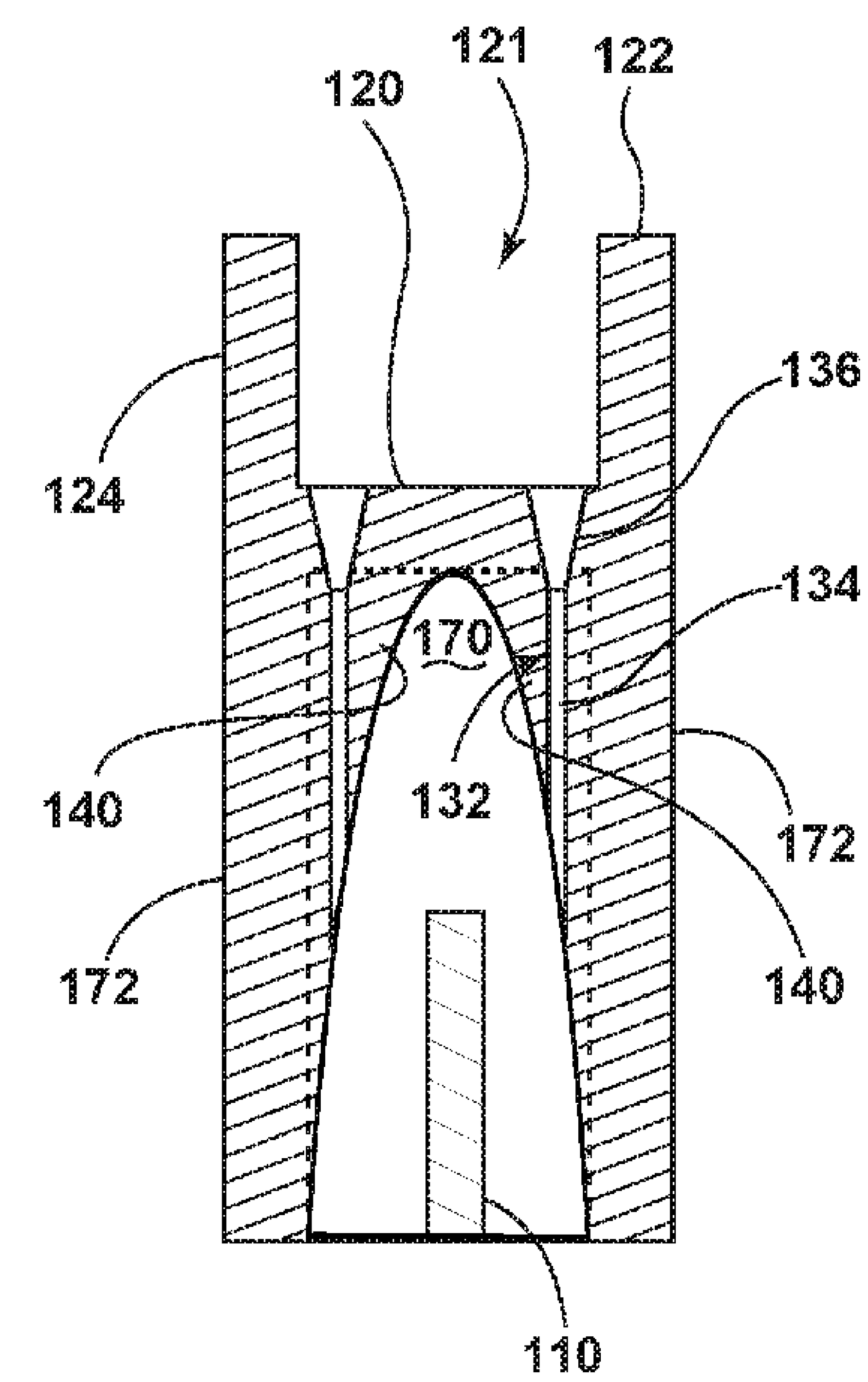
(57) **ABSTRACT**

A blade for a gas turbine engine comprises an airfoil having a pressure side and a suction side, with a root and a tip wall. The pressure side and suction side extend beyond the tip wall to define a tip channel, defining a plurality of internal and external corners. The corners comprise fillets to define a thickness being greater than the thickness for the pressure, suction, or tip walls. A film hole can extend through the fillet, such that the length of the film hole at the fillet can be increased to define an increased length-to-diameter ratio for the film hole to improve film cooling through the film hole.

27 Claims, 10 Drawing Sheets



(52) **U.S. Cl.**
CPC .. *F05D 2240/307* (2013.01); *F05D 2260/202* (2013.01); *Y02T 50/60* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,688,104	A	11/1997	Beabout	
5,738,491	A	4/1998	Lee	
6,494,678	B1	12/2002	Bunker	
6,527,514	B2 *	3/2003	Roeloffs	F01D 5/186 416/97 R
6,602,052	B2	8/2003	Liang	
6,994,514	B2 *	2/2006	Soechting	F01D 5/187 415/115
7,118,342	B2	10/2006	Lee	
7,249,933	B2	7/2007	Lee et al.	
7,510,376	B2	3/2009	Lee	
7,857,587	B2	12/2010	Correia	
7,922,451	B1	4/2011	Liang	
7,997,865	B1	8/2011	Liang	
8,435,004	B1 *	5/2013	Liang	F01D 5/187 416/92
8,545,180	B1	10/2013	Liang	
8,684,691	B2	4/2014	Lee	
8,727,725	B1	5/2014	Liang	
8,777,567	B2	7/2014	Poon	
9,156,114	B2	10/2015	Pal	
9,605,544	B2	3/2017	Tibbott et al.	
9,630,277	B2	4/2017	Lee	
2004/0094287	A1	5/2004	Wang	
2005/0232771	A1	10/2005	Harvey et al.	
2008/0166240	A1	7/2008	Scott et al.	
2009/0208325	A1	8/2009	Devore et al.	
2011/0223005	A1	9/2011	Lee et al.	
2012/0070307	A1	3/2012	Poon et al.	
2012/0282108	A1	11/2012	Lee	
2013/0302179	A1	11/2013	Bergholz	
2013/0312941	A1	11/2013	Bunker	
2015/0044029	A1	2/2015	Tibbott et al.	
2017/0089206	A1 *	3/2017	Quach	F01D 5/187
2017/0144252	A1	5/2017	Arjakine	

FOREIGN PATENT DOCUMENTS

EP	1 422 383	A2	5/2004
EP	1 650 404	A2	4/2006
EP	1 762 701	A2	3/2007
EP	1 793 087	A1	6/2007
EP	2 378 076	A1	10/2011
EP	2685048	A1	1/2014

* cited by examiner

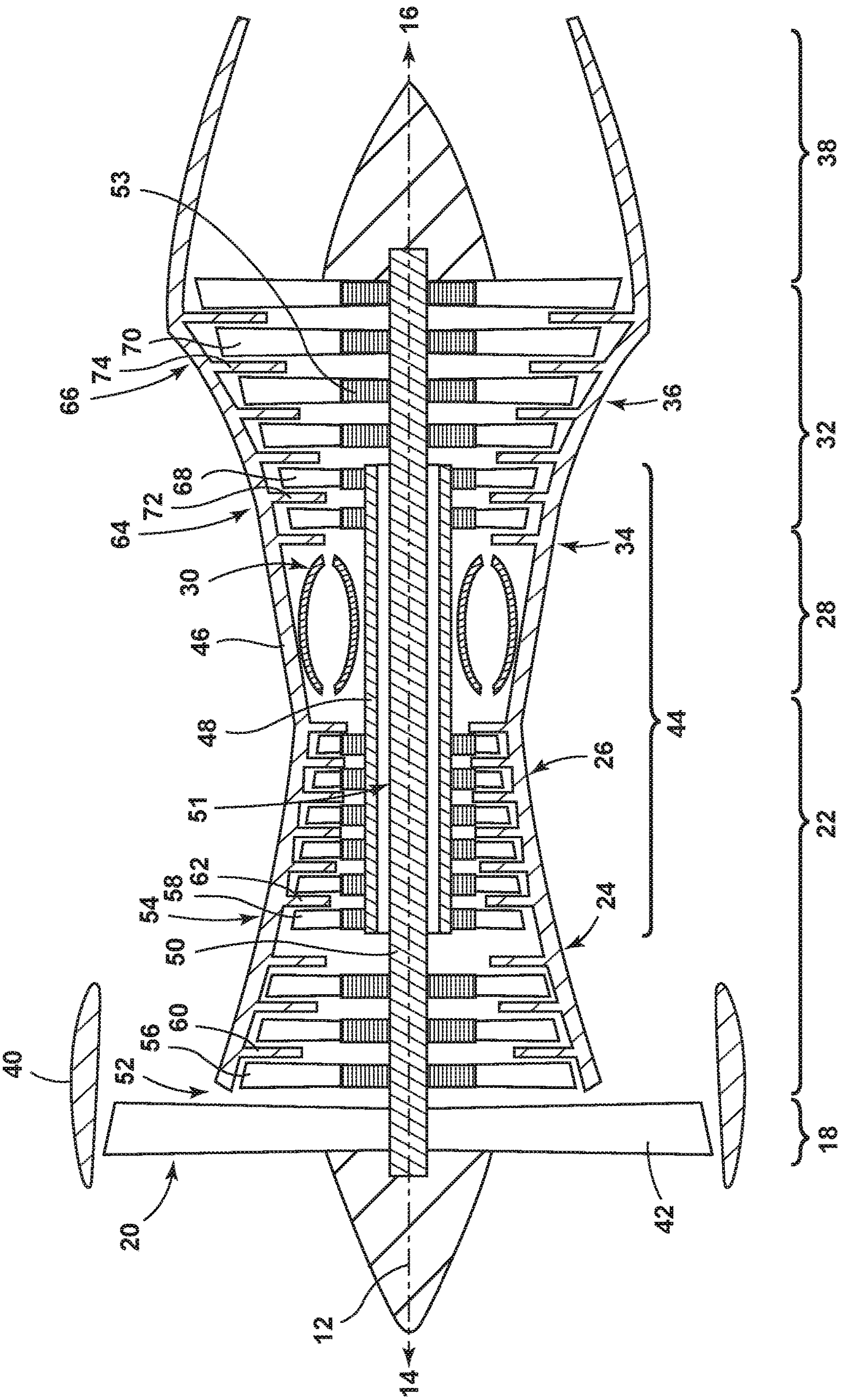

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FIG. 1

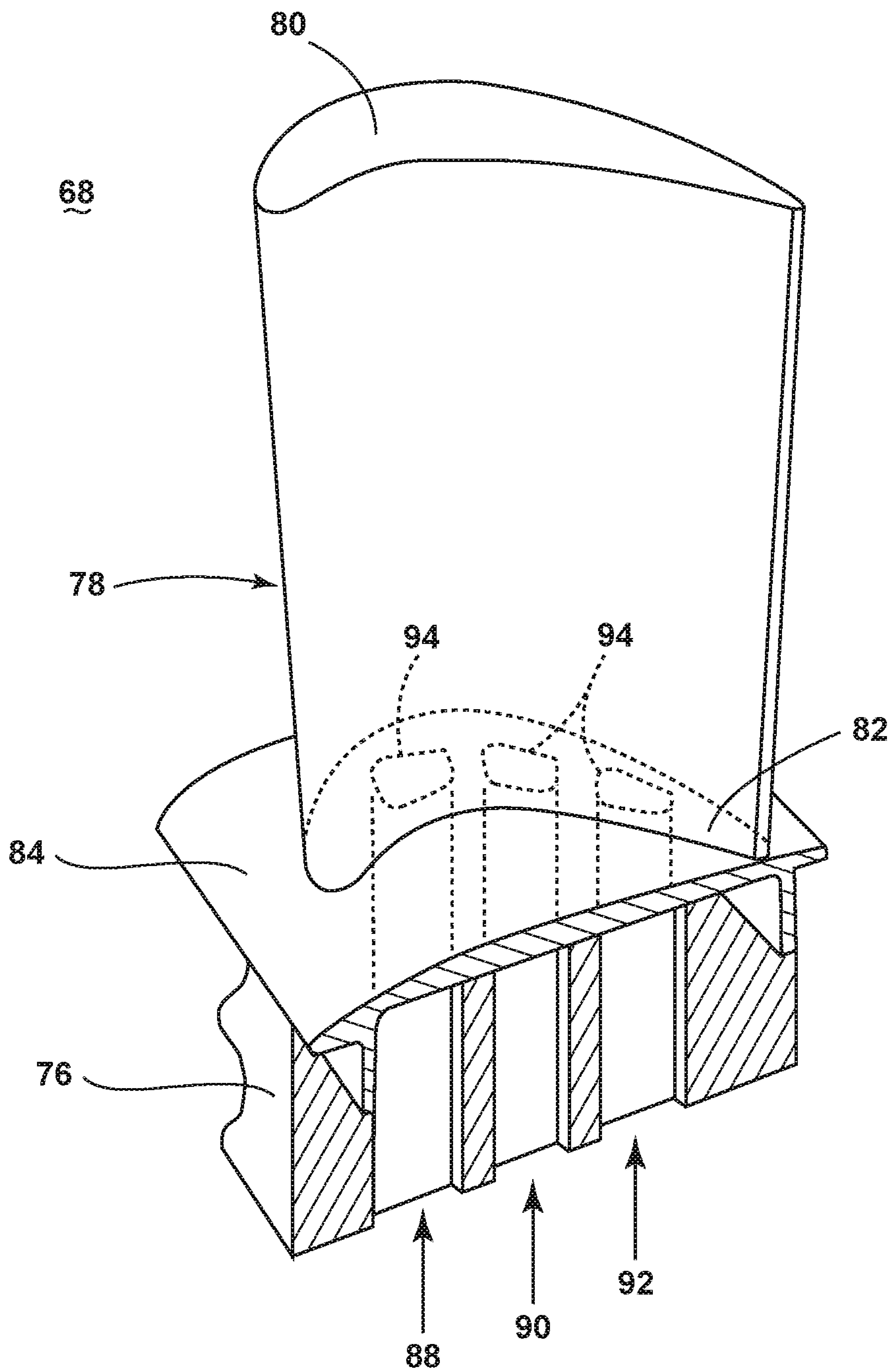


FIG. 2

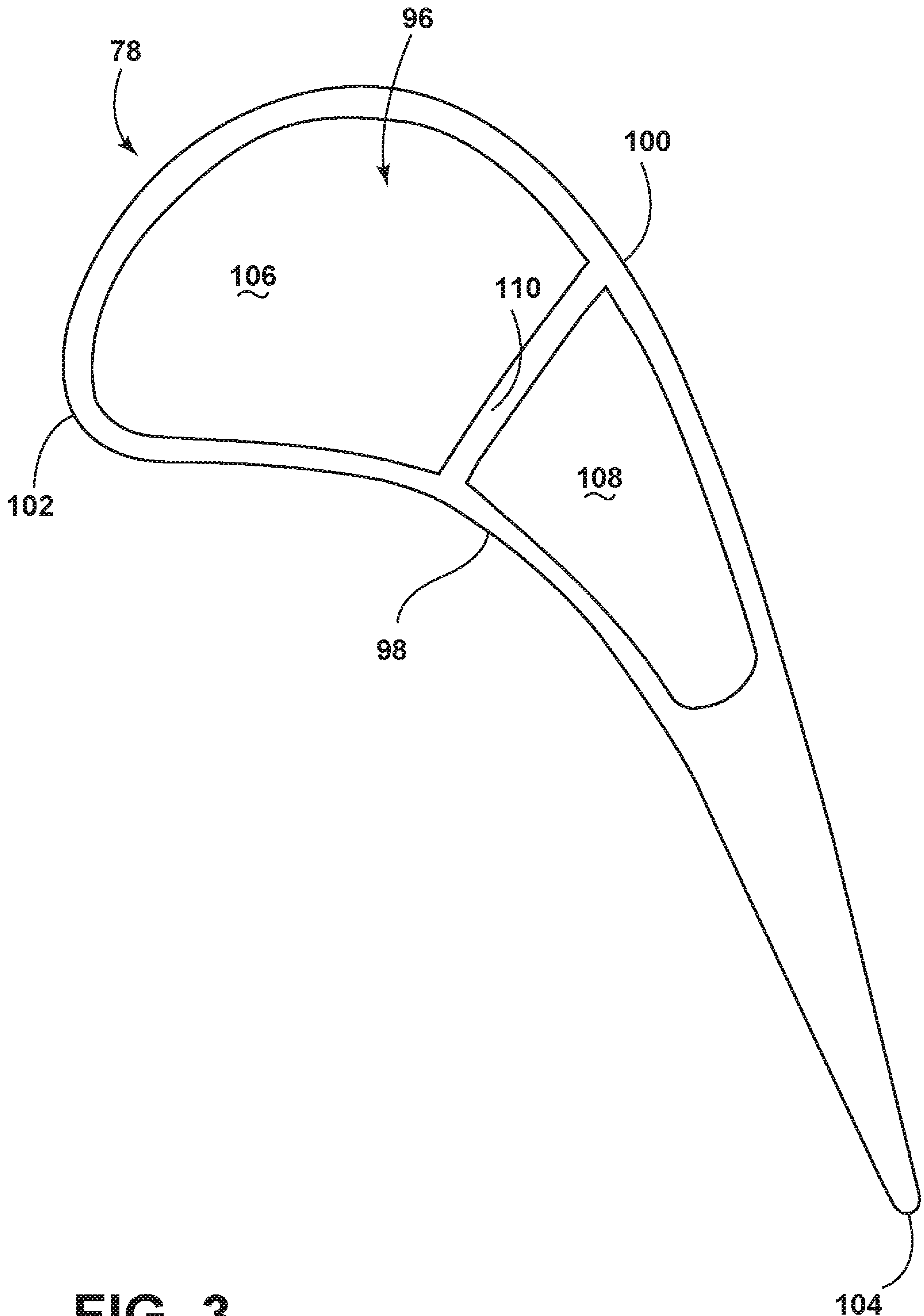
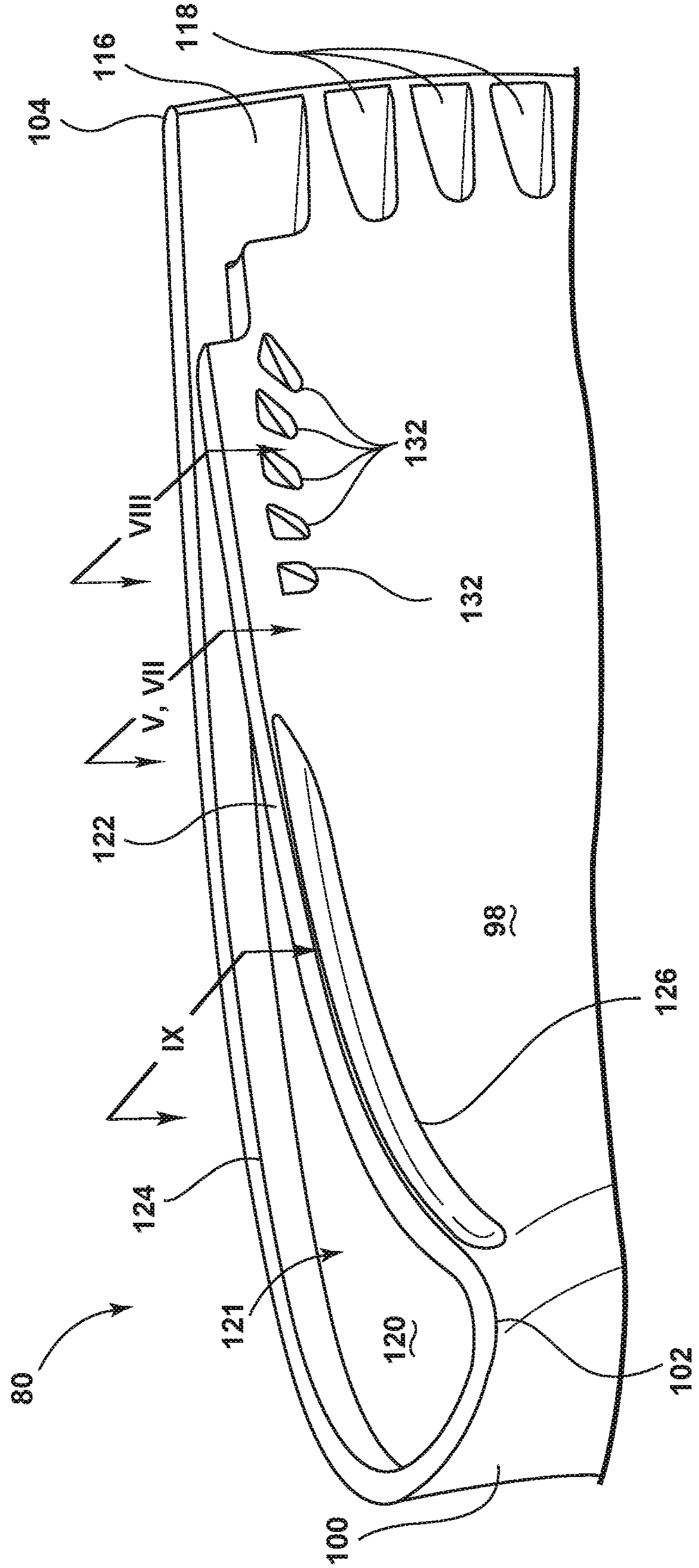


FIG. 3



118
116
104
132
VIII
132
V, VII
122
98
126
IX
124
121
120
80
102
100

FIG. 4

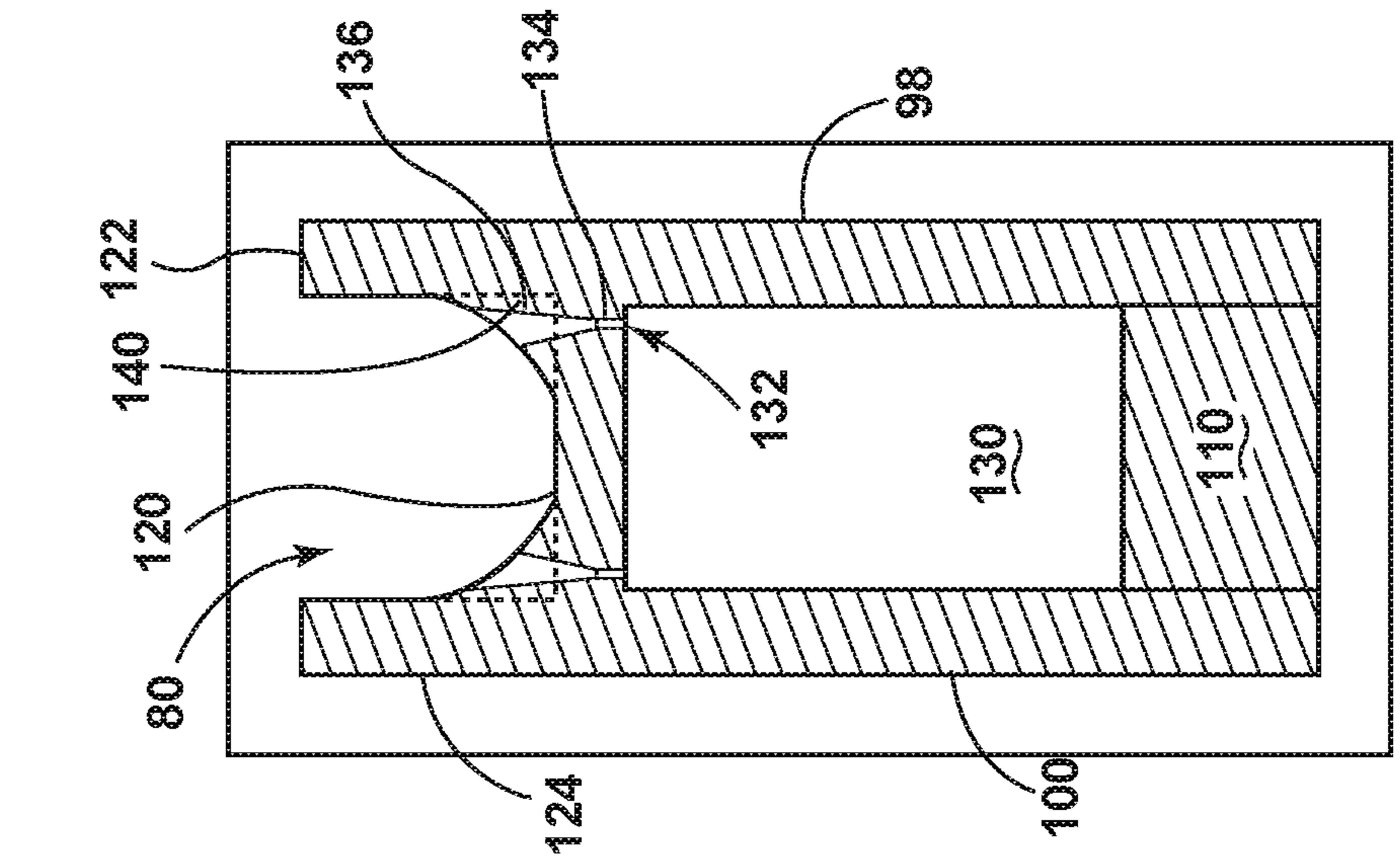


FIG. 5C

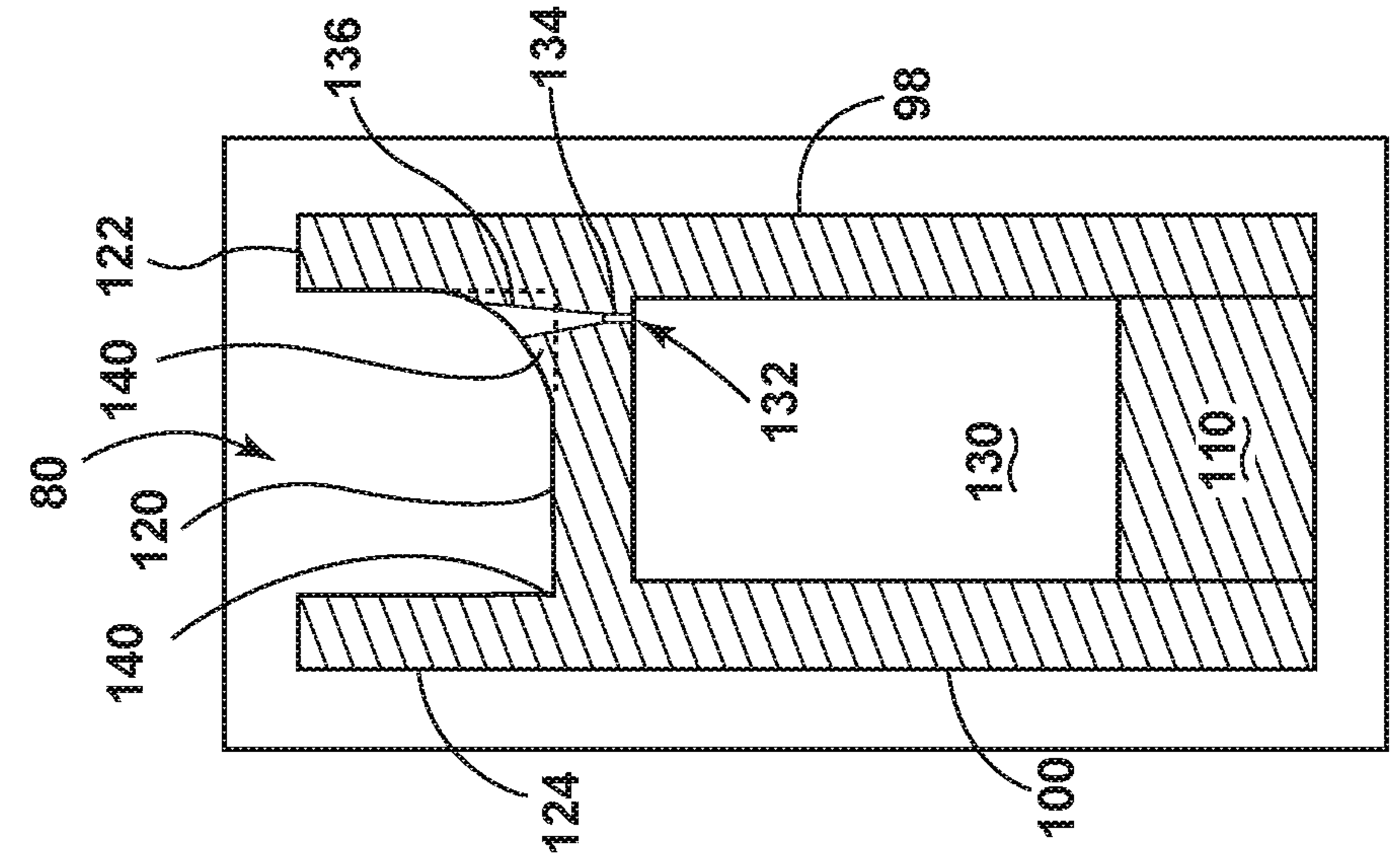


FIG. 5B

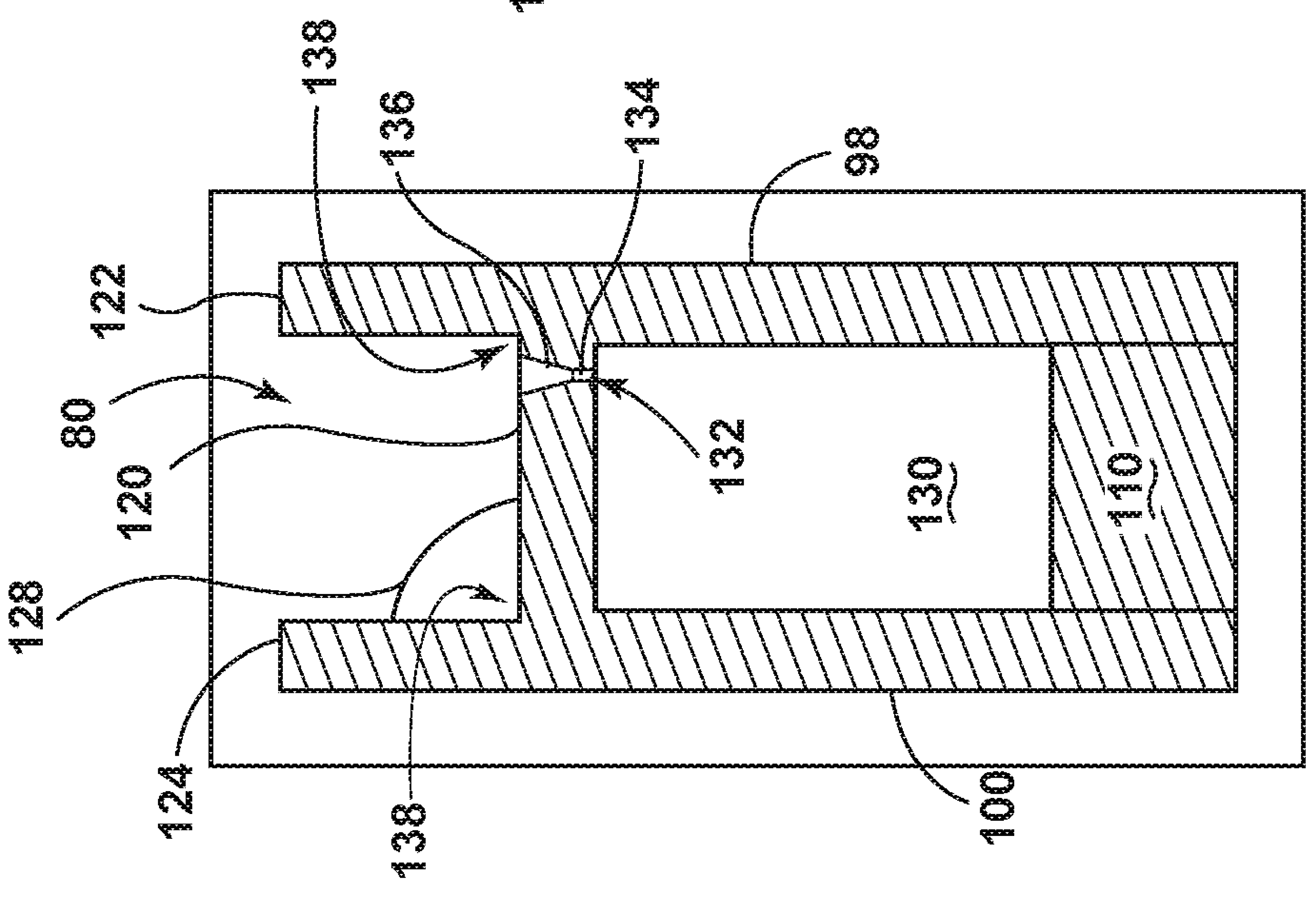


FIG. 5A
(Prior Art)

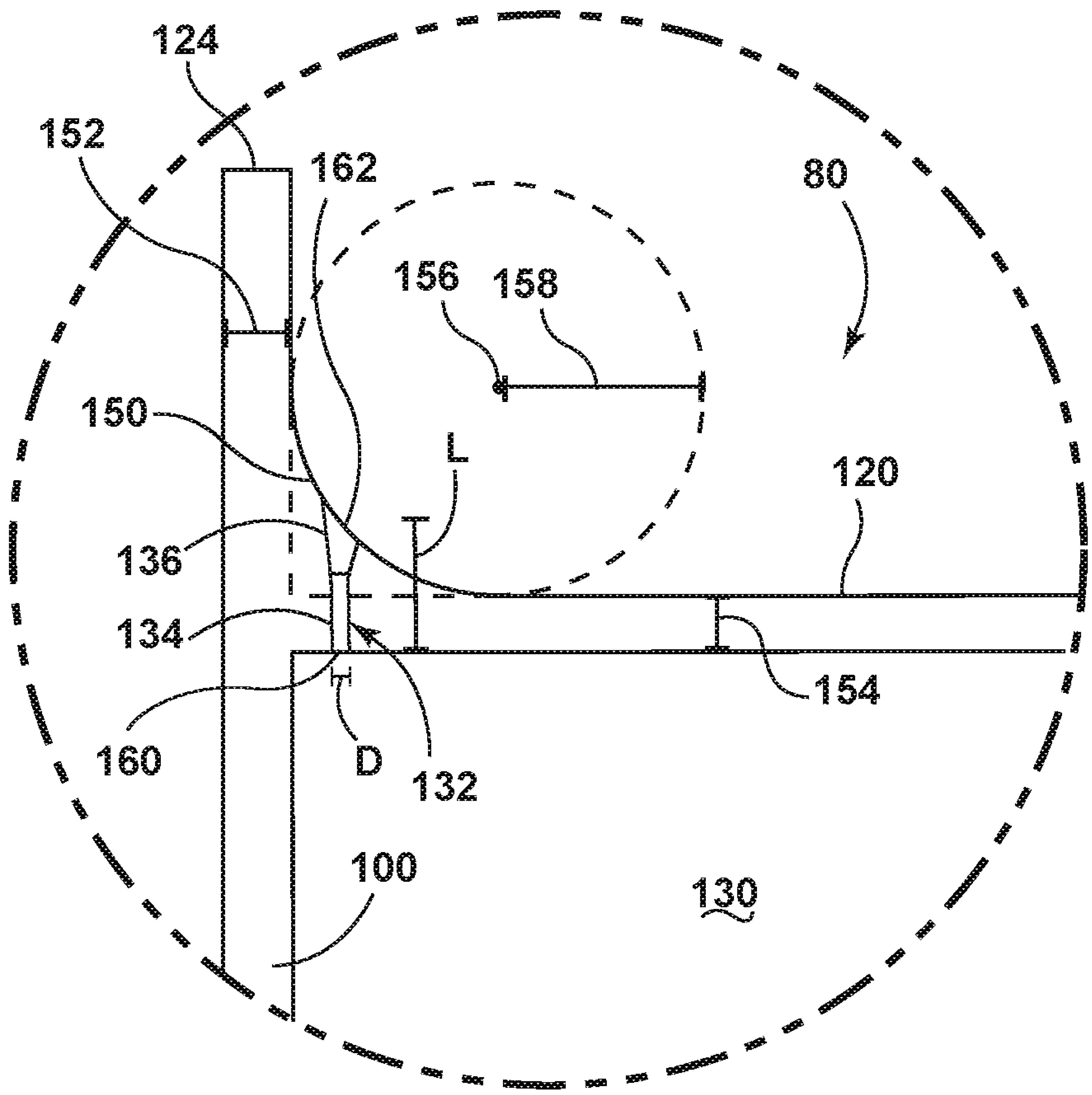


FIG. 6

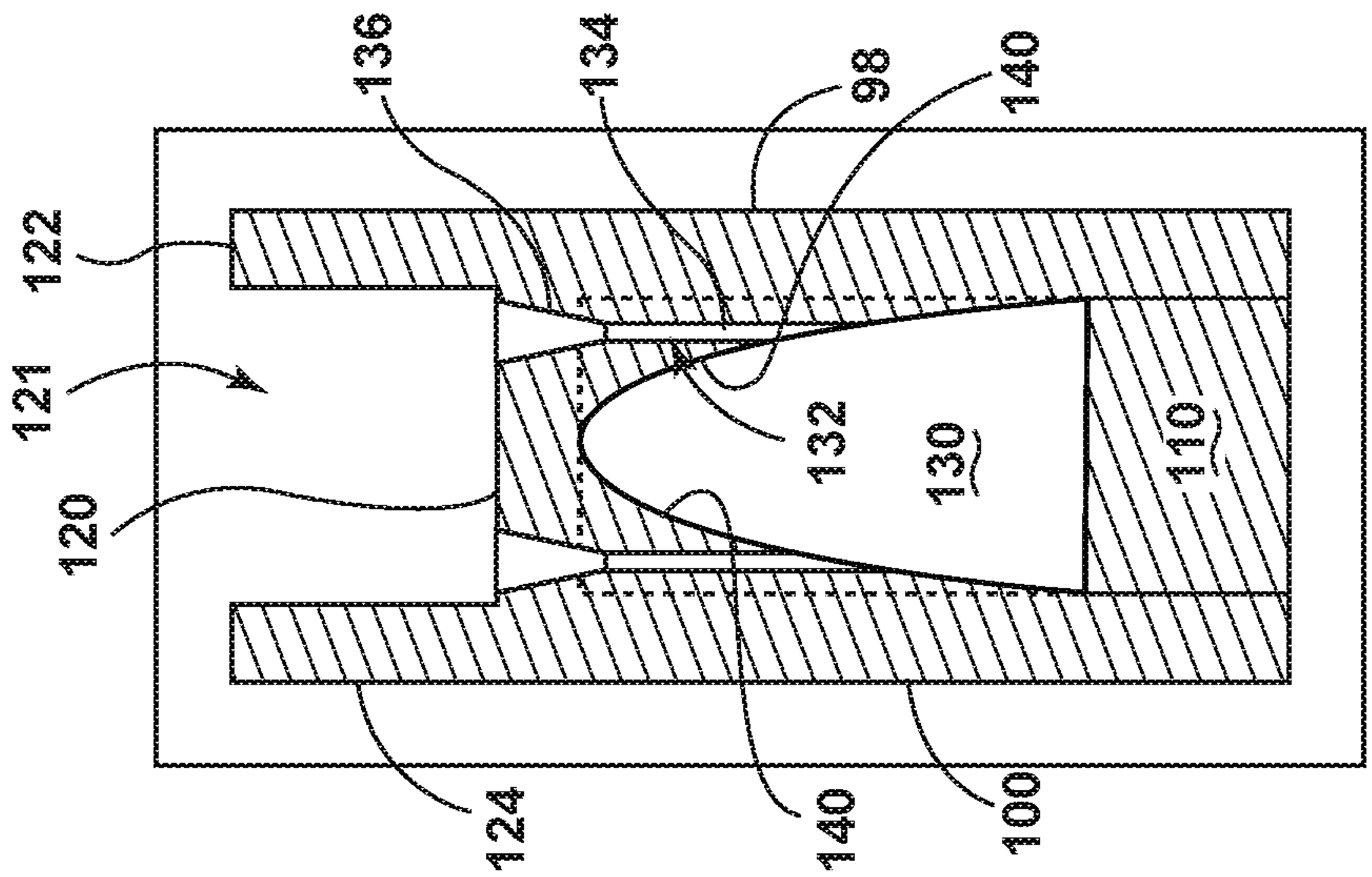


FIG. 7C

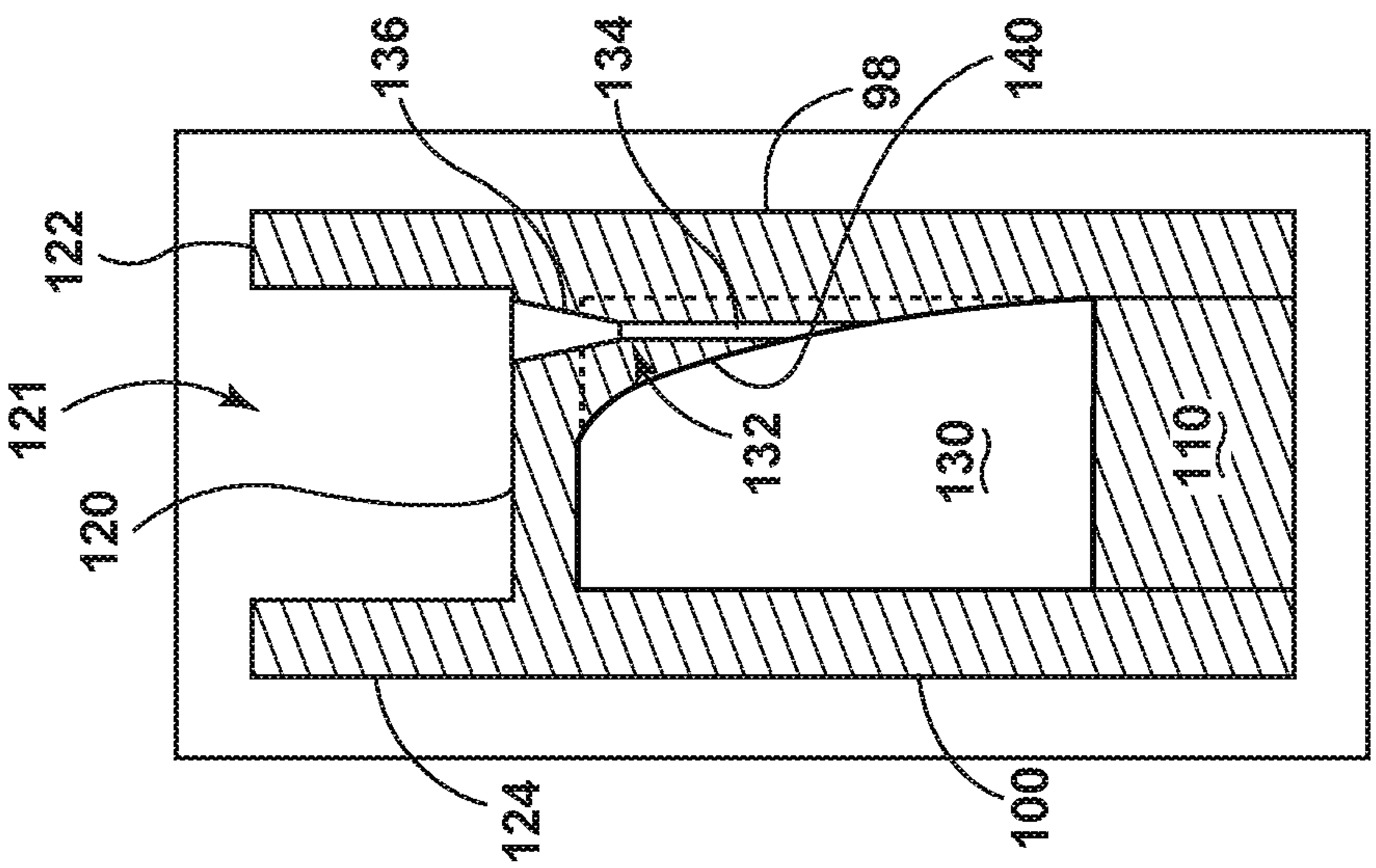


FIG. 7B

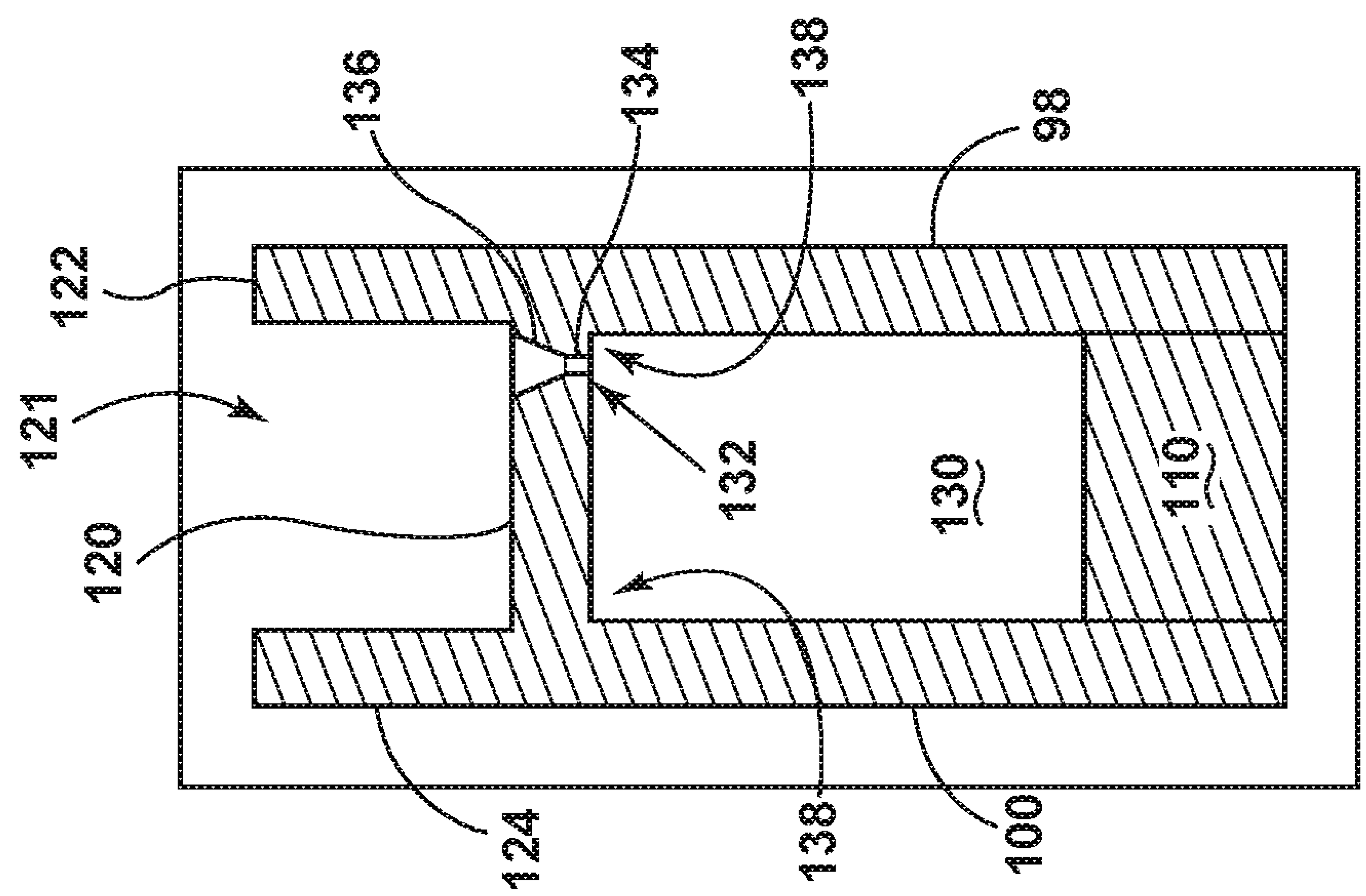


FIG. 7A
(Prior Art)

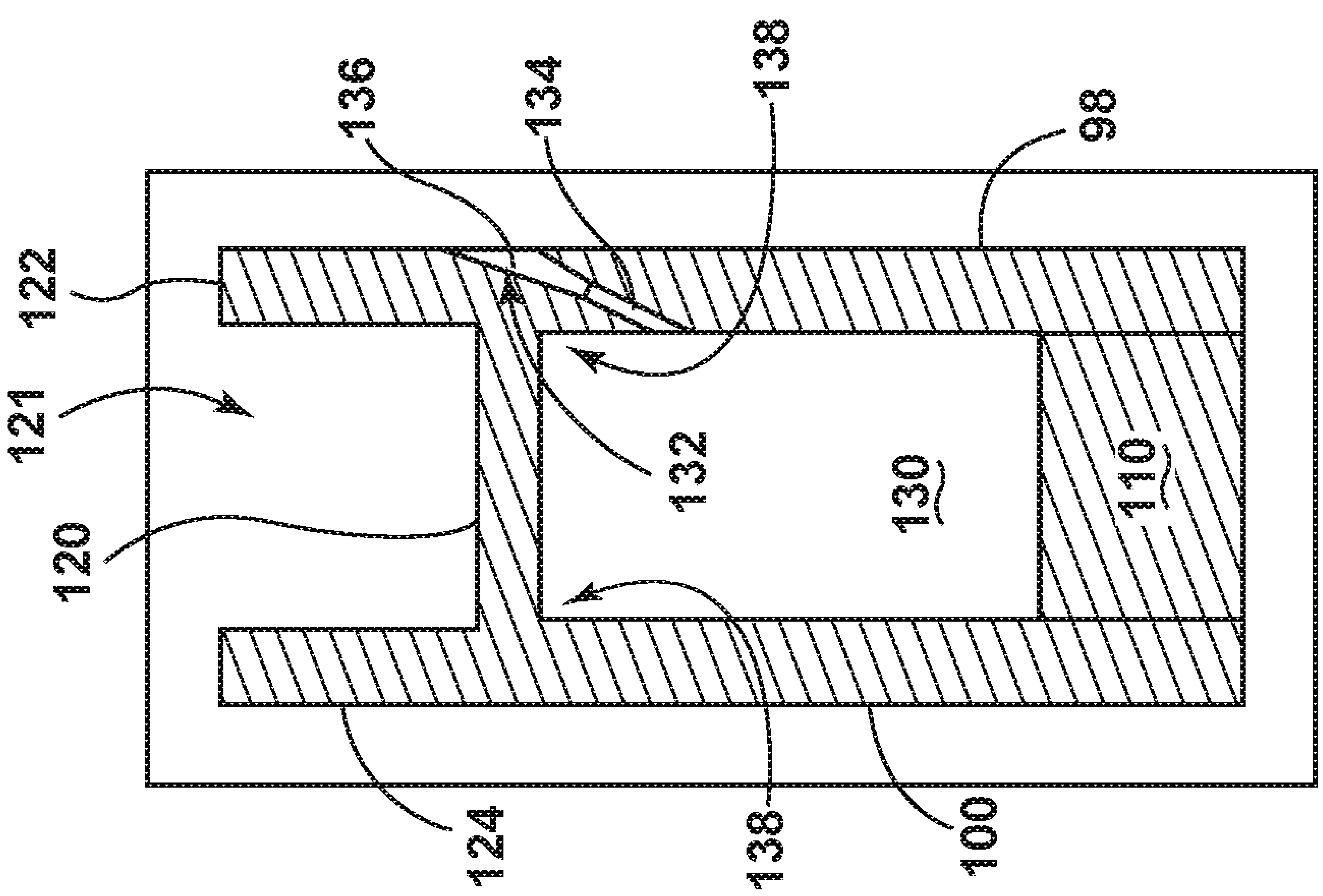


FIG. 8A (Prior Art)

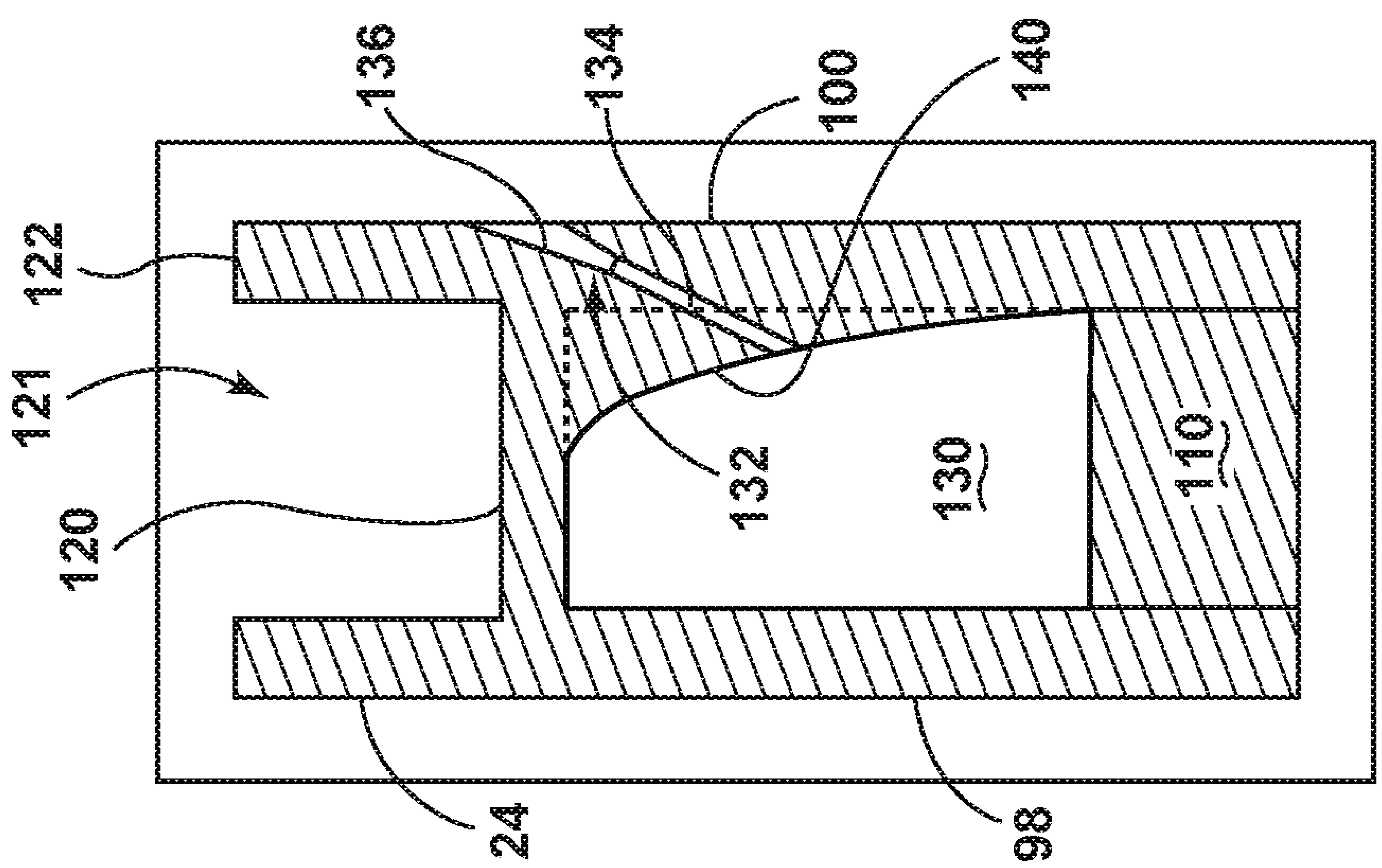


FIG. 8B

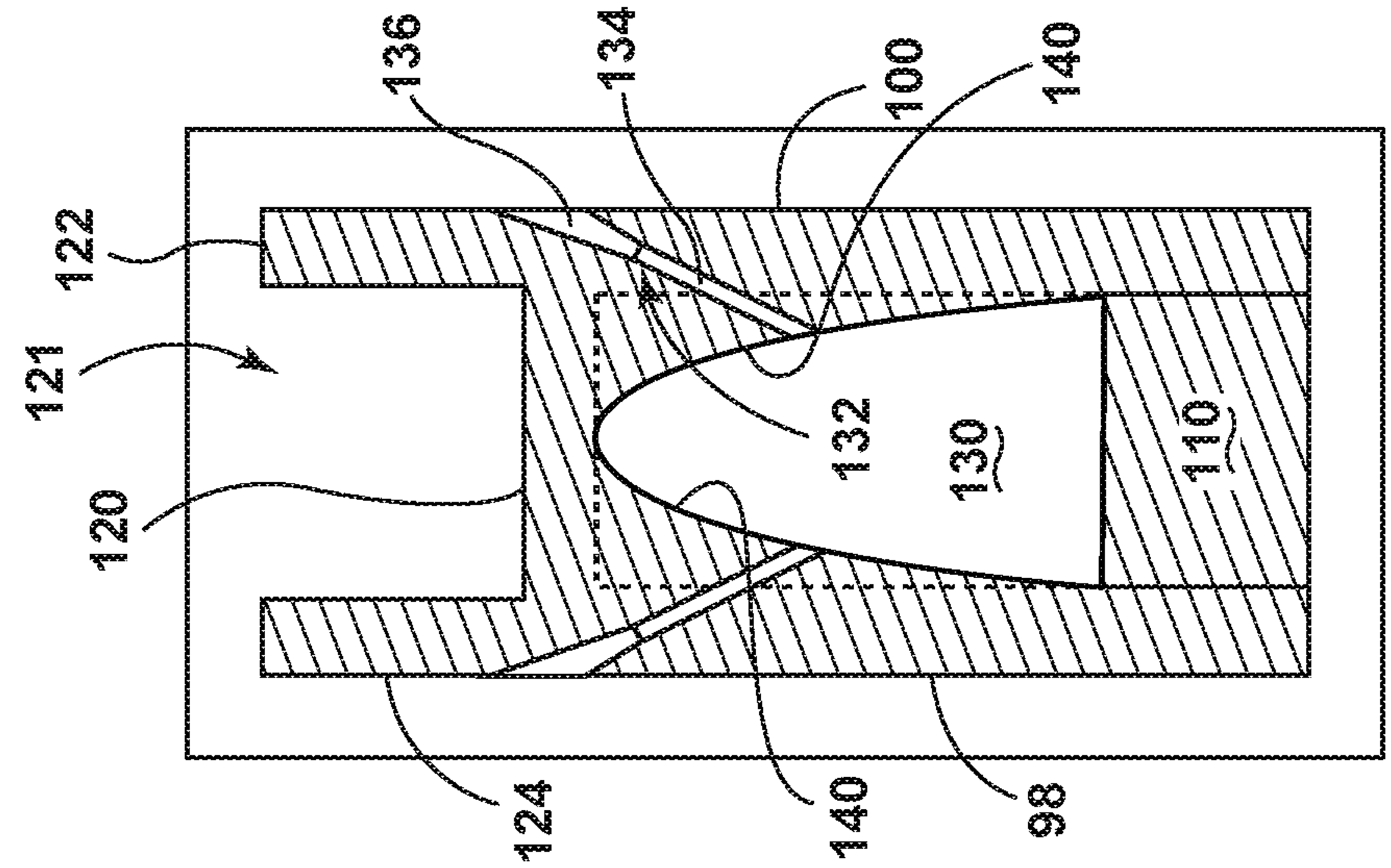


FIG. 8C

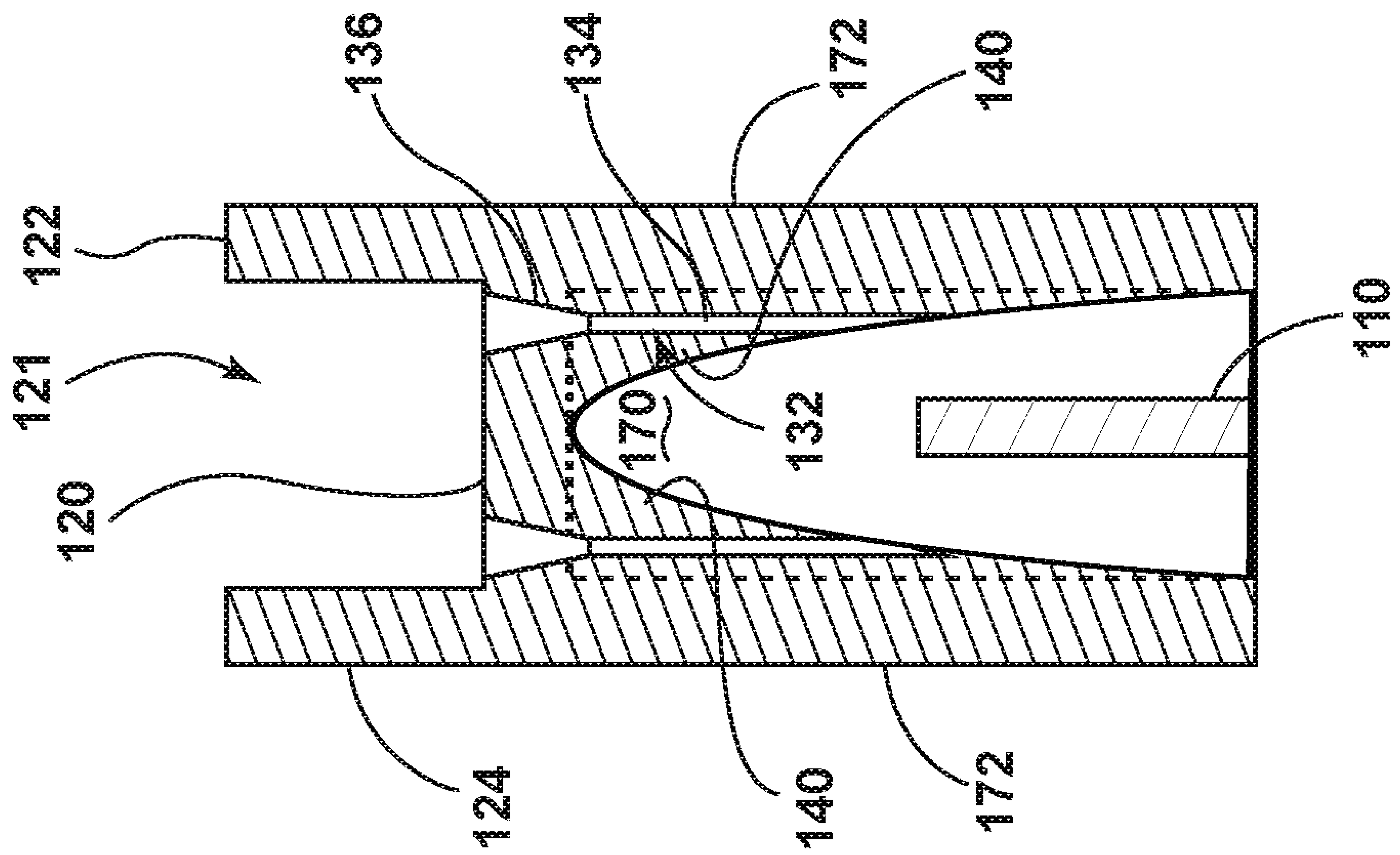


FIG. 9C

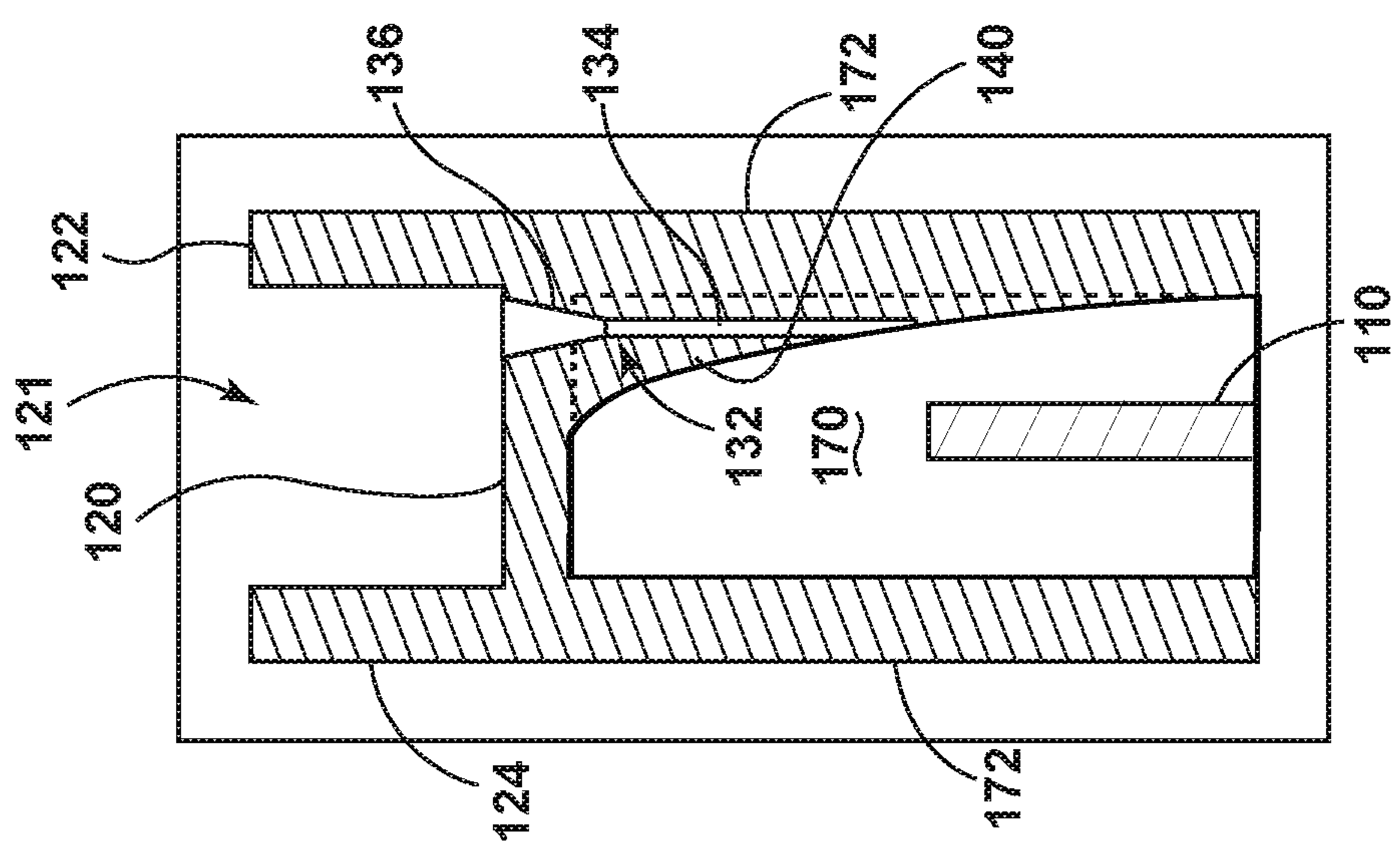


FIG. 9B

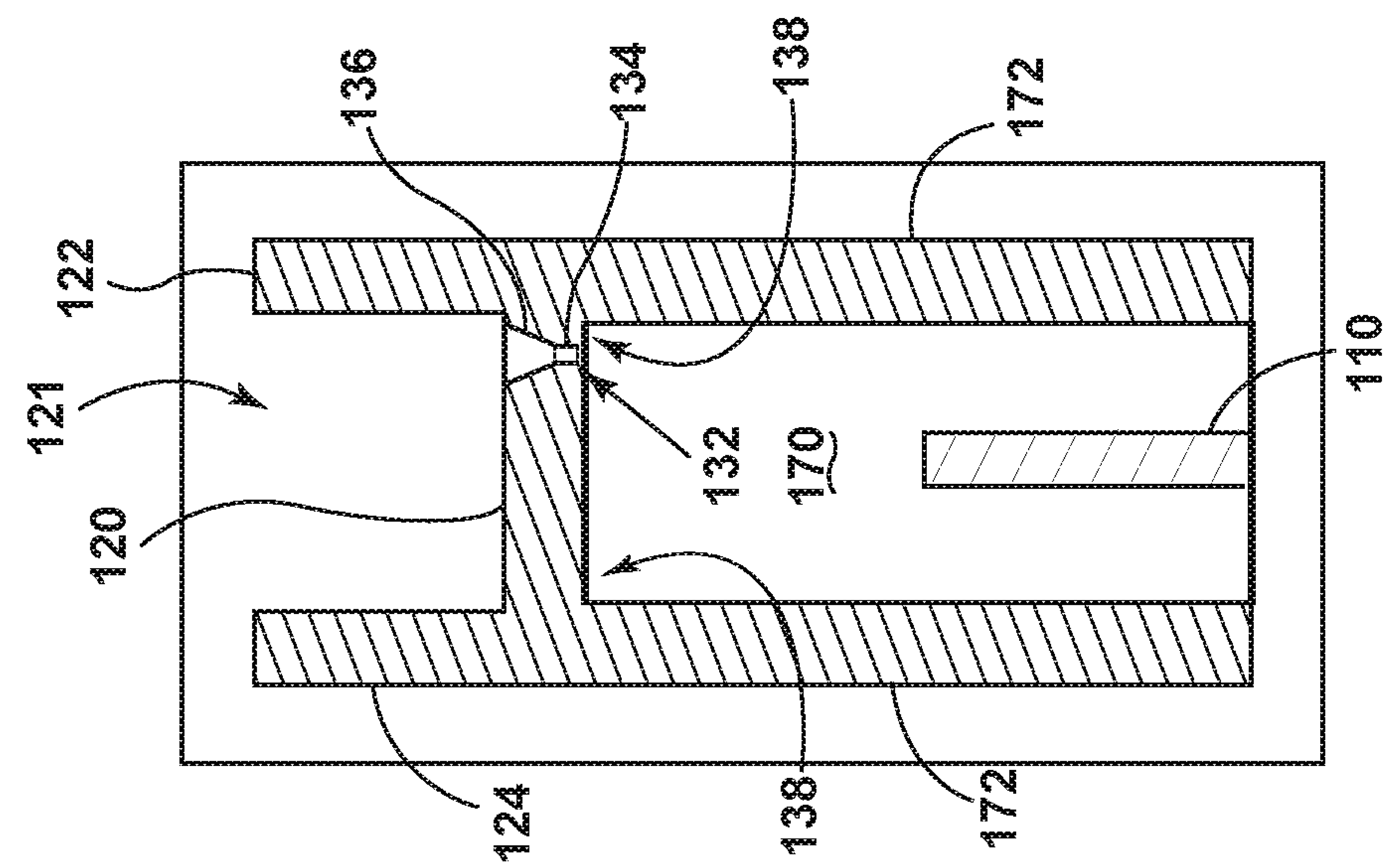


FIG. 9A
(Prior Art)

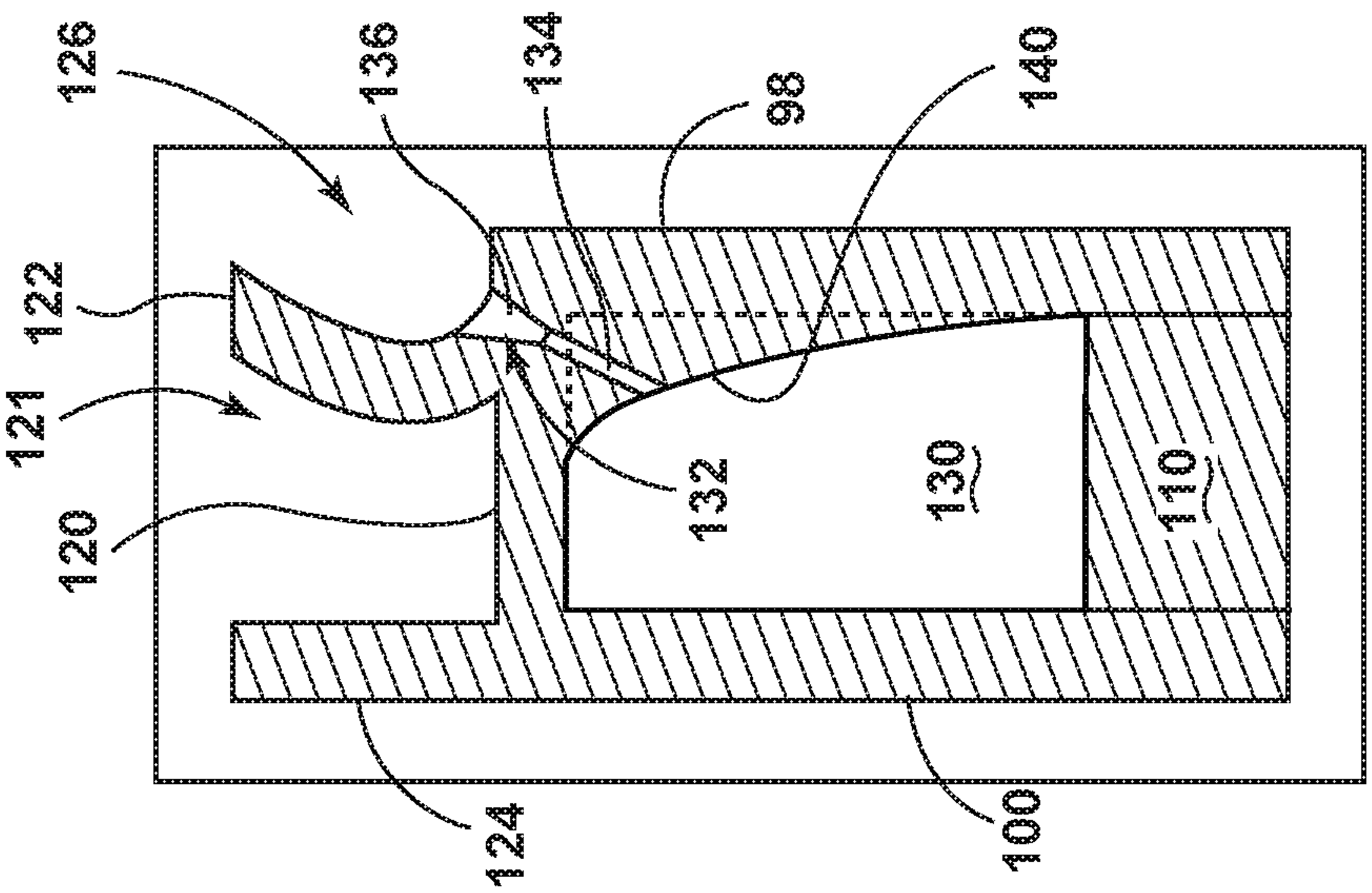


FIG. 10B

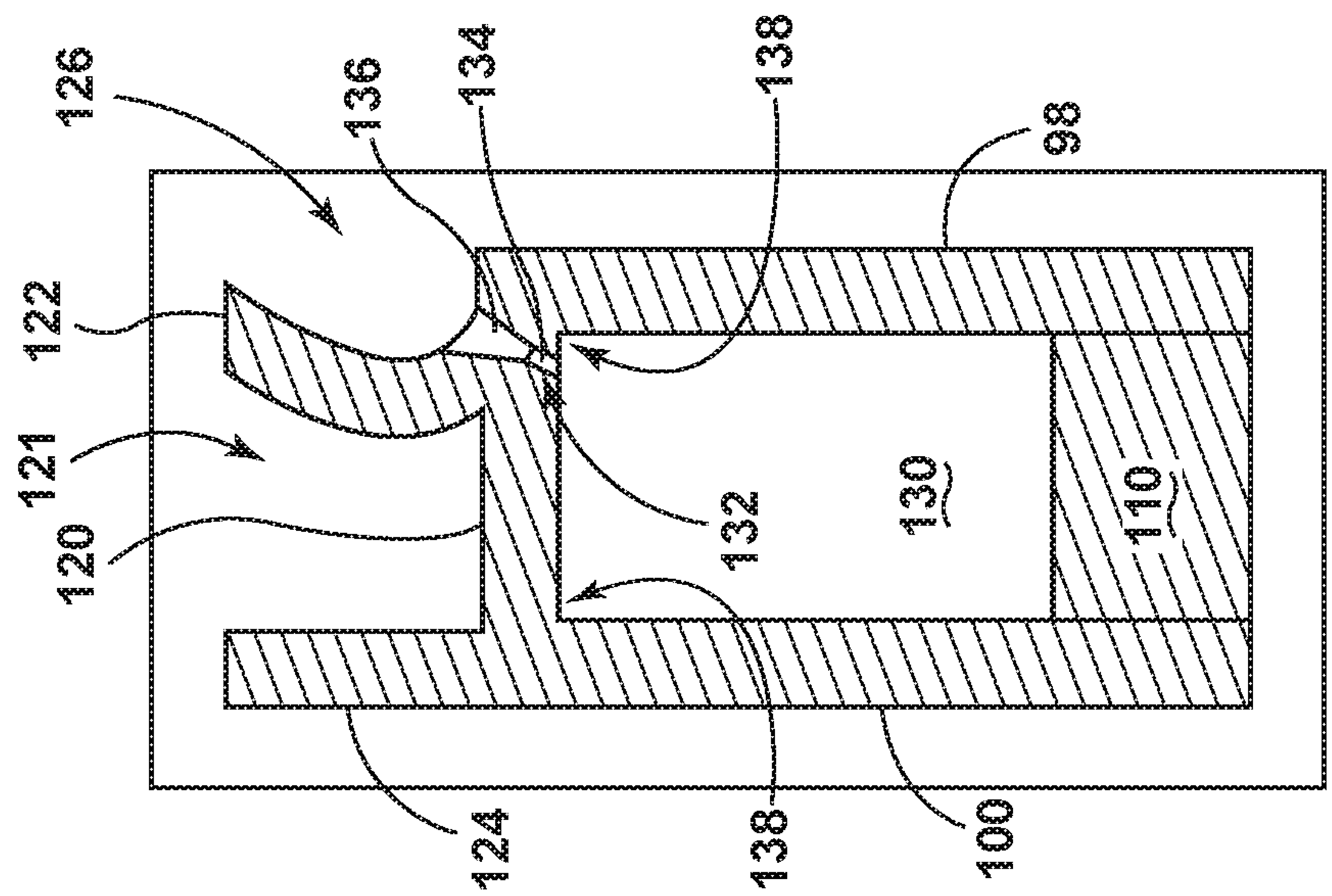


FIG. 10A

FILLET OPTIMIZATION FOR TURBINE AIRFOIL

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a division of U.S. application Ser. No. 14/960,991, filed on Dec. 7, 2015, titled "FILLET OPTIMIZATION FOR TURBINE AIRFOIL", which is herein incorporated by reference.

BACKGROUND OF THE INVENTION

Turbine engines, and particularly gas or combustion turbine engines, are rotary engines that extract energy from a flow of combusted gases passing through the engine in a series of compressor stages, which include pairs of rotating blades and stationary vanes, through a combustor, and then onto a multitude of turbine blades. Gas turbine engines have been used for land and nautical locomotion and power generation, but are most commonly used for aeronautical applications such as for airplanes, including helicopters. In airplanes, gas turbine engines are used for propulsion of the aircraft.

Gas turbine engines for aircraft are designed to operate at high temperatures to maximize engine efficiency, so cooling of certain engine components, such as the high pressure turbine and the low pressure turbine, can be beneficial. Typically, cooling is accomplished by ducting cooler air from the high and/or low pressure compressors to the engine components that require cooling. Temperatures in the high pressure turbine are around 1000° C. to 2000° C. and the cooling air from the compressor is around 500° C. to 700° C. While the compressor air is a high temperature, it is cooler relative to the turbine air, and can be used to cool the turbine.

Contemporary turbine blades, as well as vanes or nozzles, generally include one or more interior cooling circuits for routing the cooling air through the blade to cool different portions of the blade, and can include dedicated cooling circuits for cooling different portions of the blade, such as the leading edge, trailing edge and tip of the blade.

BRIEF DESCRIPTION OF THE INVENTION

In one aspect, a blade for a gas turbine engine comprising an airfoil having an outer wall defining a pressure side and a suction side, the outer wall extending chord-wise from a leading edge to a trailing edge and span-wise from a root toward a tip. The blade further comprises a tip channel spanning the pressure side and the suction side of the outer wall and intersecting the outer wall to form at least one corner, with the outer wall having a first thickness at the corner and the tip channel having a second thickness at the corner. The blade further has a cooling passage having a portion located along the tip channel and at least partially defined by the tip channel and the outer wall such that the corner defines a corner of the cooling passage. Further still, the blade comprises a fillet located at the corner having an effective radius of at least 1.5 times larger than the greater of the first and second thicknesses and at least one film hole extending through the fillet to fluidly couple the cooling passage to an exterior of the airfoil.

In another aspect, a method of forming a film holes in a blade of a gas turbine engine comprising forming the film hole through a fillet of a corner of a cooling passage formed by the intersection of a tip channel and an outer wall, with the fillet having an effective radius of at least 1.5 times greater than the greater of the thicknesses for the tip channel and the outer wall.

In another aspect, a blade for a gas turbine engine comprising an airfoil having an internal cooling passage at least partially formed by intersecting a tip channel and an outer wall defining a corner having a fillet with an effective radius of at least 1.5 times the thickness of the thickest of the intersecting tip channel and outer wall and at least one film holes extending through the fillet and at least one of the tip channel and outer wall.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. **1** is a schematic cross-sectional diagram of a gas turbine engine for an aircraft.

FIG. **2** is a perspective view of an engine component in the form of a turbine blade of the engine of FIG. **1** with cooling air inlet passages.

FIG. **3** is a cross-sectional view of the airfoil of FIG. **2**.

FIG. **4** is a perspective view of a tip of the airfoil of FIG. **2** illustrating a tip channel and a tip shelf.

FIGS. **5**A-**5**C are cross-sectional views of section V of FIG. **4** illustrating an increased film hole length by placing a fillet in the tip channel.

FIG. **6** is a schematic view illustrating the increased film hole length with an external fillet at the tip of the airfoil.

FIGS. **7**A-**7**C are cross-sectional views of section VII of FIG. **4** illustrating the increased film hole length by placing a fillet internal of the airfoil adjacent to the tip channel.

FIGS. **8**A-**8**C are cross-sectional views of section VIII of FIG. **4** illustrating the increased film hole length with an internal fillet having the film hole extending to a sidewall.

FIGS. **9**A-**9**C are cross-sectional views of section VIII of FIG. **4** illustrating the increased film hole length with an internal fillet within an internal serpentine circuit.

FIGS. **10**A-**10**B are cross-sectional views of section IX of FIG. **4** illustrating the increased film hole length with an internal fillet having the film hole extending to a tip shelf.

DESCRIPTION OF EMBODIMENTS OF THE INVENTION

The described embodiments of the present invention are directed to apparatuses, methods, and other devices related to routing airflow in a turbine engine. For purposes of illustration, the present invention will be described with respect to an aircraft gas turbine engine. It will be understood, however, that the invention is not so limited and can have general applicability in non-aircraft applications, such as other mobile applications and non-mobile industrial, commercial, and residential applications.

It should be further understood that for purposes of illustration, the present invention will be described with respect to an airfoil for a turbine blade of the turbine engine. It will be understood, however, that the invention is not limited to the turbine blade, and can comprise any airfoil structure, such as a compressor blade, a turbine or compressor vane, a fan blade, or a strut in non-limiting examples. Furthermore, the filleted optimization can have uses in additional engine components utilizing film holes or surface film cooling, such as a band, combustor assembly, or platform in non-limiting examples.

As used herein, the term "forward" or "upstream" refers to moving in a direction toward the engine inlet, or a component being relatively closer to the engine inlet as compared to another component. The term "aft" or "downstream" used in conjunction with "forward" or "upstream" refers to a direction toward the rear or outlet of the engine relative to the engine centerline.

Additionally, as used herein, the terms "radial" or "radially" refer to a dimension extending between a center longitudinal axis of the engine and an outer engine circumference.

All directional references (e.g., radial, axial, proximal, distal, upper, lower, upward, downward, left, right, lateral, front, back, top, bottom, above, below, vertical, horizontal, clockwise, counterclockwise, upstream, downstream, aft, etc.) are only used for identification purposes to aid the reader's understanding of the present invention, and do not create limitations, particularly as to the position, orientation, or use of the invention. Connection references (e.g., attached, coupled, connected, and joined) are to be construed broadly and can include intermediate members between a collection of elements and relative movement between elements unless otherwise indicated. As such, connection references do not necessarily infer that two elements are directly connected and in fixed relation to one another. The exemplary drawings are for purposes of illustration only and the dimensions, positions, order and relative sizes reflected in the drawings attached hereto can vary.

It should be further understood that as used herein, the term 'fillet' is used to describe material that "fills" in a corner formed by a junction of two intersecting walls. It should be further understood that the intersecting walls can be integral and need not comprise separate intersecting elements. Similarly, the fillet can be integral with the intersecting walls. In the case of the fillet being integral to the intersecting walls, there is no clear demarcation between the fillet and the corner. In such a case, the fillet can be identified by virtually extending the wall thickness until the walls intersect to form a virtual corner.

FIG. **1** is a schematic cross-sectional diagram of a gas turbine engine **10** for an aircraft. The engine **10** has a generally longitudinally extending axis or centerline **12** extending forward **14** to aft **16**. The engine **10** includes, in downstream serial flow relationship, a fan section **18** including a fan **20**, a compressor section **22** including a booster or low pressure (LP) compressor **24** and a high pressure (HP) compressor **26**, a combustion section **28** including a combustor **30**, a turbine section **32** including a HP turbine **34**, and a LP turbine **36**, and an exhaust section **38**.

The fan section **18** includes a fan casing **40** surrounding the fan **20**. The fan **20** includes a plurality of fan blades **42** disposed radially about the centerline **12**. The HP compressor **26**, the combustor **30**, and the HP turbine **34** form a core **44** of the engine **10**, which generates combustion gases. The core **44** is surrounded by core casing **46**, which can be coupled with the fan casing **40**.

A HP shaft or spool **48** disposed coaxially about the centerline **12** of the engine **10** drivingly connects the HP turbine **34** to the HP compressor **26**. A LP shaft or spool **50**, which is disposed coaxially about the centerline **12** of the engine **10** within the larger diameter annular HP spool **48**, drivingly connects the LP turbine **36** to the LP compressor **24** and fan **20**. The portions of the engine **10** mounted to and rotating with either or both of the spools **48**, **50** are referred to individually or collectively as a rotor **51**.

The LP compressor **24** and the HP compressor **26** respectively include a plurality of compressor stages **52**, **54**, in which a set of compressor blades **58** rotate relative to a corresponding set of static compressor vanes **60**, **62** (also called a nozzle) to compress or pressurize the stream of fluid passing through the stage. In a single compressor stage **52**, **54**, multiple compressor blades **56**, **58** can be provided in a ring and can extend radially outwardly relative to the centerline **12**, from a blade platform to a blade tip, while the corresponding static compressor vanes **60**, **62** are positioned downstream of and adjacent to the rotating blades **56**, **58**. It is noted that the number of blades, vanes, and compressor stages shown in FIG. **1** were selected for illustrative purposes only, and that other numbers are possible. The blades **56**, **58** for a stage of the compressor can be mounted to a disk **53**, which is mounted to the corresponding one of the HP and LP spools **48**, **50**, with each stage having its own disk. The vanes **60**, **62** are mounted to the core casing **46** in a circumferential arrangement about the rotor **51**.

The HP turbine **34** and the LP turbine **36** respectively include a plurality of turbine stages **64**, **66**, in which a set of turbine blades **68**, **70** are rotated relative to a corresponding set of static turbine vanes **72**, **74** (also called a nozzle) to extract energy from the stream of fluid passing through the stage. In a single turbine stage **64**, **66**, multiple turbine blades **68**, **70** can be provided in a ring and can extend radially outwardly relative to the centerline **12**, from a blade platform to a blade tip, while the corresponding static turbine vanes **72**, **74** are positioned upstream of and adjacent to the rotating blades **68**, **70**. It is noted that the number of blades, vanes, and turbine stages shown in FIG. **1** were selected for illustrative purposes only, and that other numbers are possible.

In operation, the rotating fan **20** supplies ambient air to the LP compressor **24**, which then supplies pressurized ambient air to the HP compressor **26**, which further pressurizes the ambient air. The pressurized air from the HP compressor **26** is mixed with fuel in the combustor **30** and ignited, thereby generating combustion gases. Some work is extracted from these gases by the HP turbine **34**, which drives the HP compressor **26**. The combustion gases are discharged into the LP turbine **36**, which extracts additional work to drive the LP compressor **24**, and the exhaust gas is ultimately discharged from the engine **10** via the exhaust section **38**. The driving of the LP turbine **36** drives the LP spool **50** to rotate the fan **20** and the LP compressor **24**.

Some of the ambient air supplied by the fan **20** can bypass the engine core **44** and be used for cooling of portions, especially hot portions, of the engine **10**, and/or used to cool or power other aspects of the aircraft. In the context of a turbine engine, the hot portions of the engine are normally downstream of the combustor **30**, especially the turbine section **32**, with the HP turbine **34** being the hottest portion as it is directly downstream of the combustion section **28**. Other sources of cooling fluid can be, but is not limited to, fluid discharged from the LP compressor **24** or the HP compressor **26**.

FIG. **2** is a perspective view of an engine component in the form of one of the turbine blades **68** of the engine **10** from FIG. **1**. The turbine blade **68** includes a dovetail **76** and an airfoil **78**. The airfoil **78** extends from a tip **80** to a root **82**. The dovetail **76** further includes a platform **84** integral with the airfoil **78** at the root **82**, which helps to radially contain the turbine airflow. The dovetail **76** can be configured to mount to a turbine rotor disk on the engine **10**. The dovetail **76** comprises at least one inlet passage, exemplarily shown as a first inlet passage **88**, a second inlet passage **90**, and a third inlet passage **92**, each extending through the dovetail **76** to provide internal fluid communication with the airfoil **78** at a passage outlet **94**. It should be appreciated that the dovetail **76** is shown in cross-section, such that the inlet passages **88**, **90**, **92** are housed within the body of the dovetail **76**.

Turning to FIG. **3**, the airfoil **78**, shown in cross-section, has a concave-shaped pressure sidewall **98** and a convex-shaped suction sidewall **100** which are joined together to define an airfoil shape with a leading edge **102** and a trailing edge **104**. The airfoil **78** rotates in a direction such that the pressure sidewall **98** follows the suction sidewall **100**. Thus, as shown in FIG. **3**, the airfoil **78** would rotate upward toward the top of the page.

The airfoil **78** can comprise an interior **96** with a plurality of internal passages, illustrated by example as a first passage **106** and a second passage **108**, separated by a rib **110**, which can be arranged to form one or more cooling circuits dedicated to cool a particular portion of the airfoil **78**. The passages **106**, **108** can extend radially within the airfoil **78**, from root-to-tip. It should be appreciated that the passages can comprise one or more film holes that can provide fluid communication between the particular passage and the external surface of the airfoil **78**, providing a film of cooling fluid along the external surface of the airfoil **78**.

In FIG. **4**, a perspective view best illustrates the tip **80** of the airfoil **78**. The pressure and suction sidewalls **98**, **100** extend beyond the top surface of the tip **80** such that the top surface is defined as a tip wall **120** disposed between a pressure side extension **122** and a suction side extension **124**. The combination of the tip wall **120**, and the extensions **122**, **124** can define a tip channel **121** disposed along the tip **80**. A tip shelf **126** can be defined in the pressure side extension **122** as a groove located on the pressure sidewall **98**. The airfoil **78** can further have one or more film holes **132** disposed therein, having the film holes **132** exemplarily illustrated on the pressure sidewall **98**. Additionally, the airfoil **78** can have a plurality of exit apertures shown as slot channels **118** at the trailing edge **104**, having a tip exit **116** disposed at the trailing edge adjacent the tip **80**. Alternatively, a center extension (not shown) can extend from the tip wall **120** between the pressure and suction extensions **122**, **124**, dividing the tip channel **121** into separate tip channels.

Turning now to FIGS. **5A-5C**, a cross-sectional view taken along section V of FIG. **4** illustrates a cooling passage as a tip passage **130**, which can comprise the first or second passages **106**, **108** of FIG. **3**. FIG. **5A** is a prior art tip **80** for the airfoil **78** having a film hole **132** extending between the tip passage **130** and the exterior of the airfoil **78** at the tip wall **120**. The tip passage **130** can have either a symmetrical or an asymmetrical cross-section. The film holes **132** can be a compound film hole, having a first portion **134** and a second portion **136**, which can define a metering section and a diffusing section, respectively. The compound angle of the film holes can be defined as having both an axial component and a radial component relative to the engine centerline **12**. Alternatively, the compound film hole can be defined as having a span-wise component and a chord-wise component, relative to the span and the chord of the airfoil **78**. Thus, it can be understood that although the film holes **132** are shown in cross-section being substantially radial, i.e. orthogonal to the engine centerline **12**, the film holes **132** can also extend in an axial direction relative to the engine centerline **12**, or a combination of axial and radial. Furthermore, the film holes **132** can be non-linear, defining at least a portion of an arcuate profile. The film holes **132** are not restricted to being compound. They can be axial, radial, linear, angled, compound, arcuate or otherwise in non-limiting examples. Thus, a centerline of the film hole **132** can be straight, curved, arcuate, jointed, or otherwise.

A plurality of corners **138** can be defined at the junctions between the tip wall **120** and the pressure and suction wall extensions **122**, **124**. While the corners **138** are shown as sharp corners having a defined point, it should be appreciated that they are not so limited. For example, the corners **138** can be slightly rounded, or otherwise, such that a virtual corner can be defined. A corner angle **128** can be defined at each corner **138**. The intersecting walls to define the corner **138** can intersect in a manner that defines an acute, right, or obtuse angle **128** for the corner **138**. Additionally, one or more of the intersecting walls can be angled or arcuate, such that the corner **138** comprises an increasing cross-sectional distance extending from the corner **138** at the junction between the two walls.

Turning to FIG. **5B**, the corner **138** adjacent the pressure side extension **122** and the tip wall **120** comprises a fillet **140**. The fillet **140** defines an increased thickness at the corner **138** such that the length of the film hole **132** can be extended. In FIG. **5C**, the fillets **140** can be disposed adjacent to either the pressure side extension **122**, the suction side extension **124**, or both. It should be further appreciated that nominally rounded corners are not equivalent to the fillets described herein. The fillets **140** define an increased thickness, while the slightly rounded corner can be nominal.

Turning now to FIG. **6**, the fillet **140** as shown is exemplary and should be understood that the fillets **140** are a material filling the corner **138** at the junction of intersecting walls, defining an increased thickness. The geometries as shown in FIG. **6** should be understood as exemplary, and should not be construed as limiting of the invention. Alternatively, the fillet **140** could be defined as a compound fillet, having discrete arcuate or linear surfaces defining the fillet **140**.

A length L can be defined as the length between an inlet **160** and an outlet **162** of the film hole **132** and a diameter D can be defined as the cross-sectional width of the film hole **132**. The length can be determined as the distance between the inlet **160** and the outlet **162** through the center of the film hole **132** where the centerline intersects the airfoil surface. As such, the film hole **132** can be defined by the length-to-diameter ratio, L/D. While the film holes **132** are illustrated as having an increasing cross-sectional area at the second portion **136**, it should be understood that the film holes **132** can comprise a consistent diameter D and cross-sectional area. Alternatively, the centerline of the film hole **132** can be straight, curved, arcuate, jointed, and any other suitable shape in non-limiting examples.

The suction sidewall **100** and the suction sidewall extension **124** can have a thickness **152** defined as a width for the wall. Similarly, the tip wall **120** can have a thickness **154**. The increased thickness of the fillet **140** can be defined against the virtual extensions of the walls **120**, **124**, shown in dashed line, such that the extensions **120**, **124** at the fillet **140** have an increased thickness being greater than the thicknesses **152**, **154** of the respective walls **120**, **124**. It should be understood that the fillets **140** need not comprise additional material, but can be integral with at least one of the walls **120**, **124** and can define a thickness against the virtual extensions of the walls **120**, **124** shown in dashed lines adjacent the fillet **140**. It should be further appreciated that the virtual extensions of the walls are for illustrative purposes, providing the reader with a means of visual comparison of the thickness of the fillet **140** against the wall thicknesses **120**, **124**, and such an extension of the walls adjacent the fillet **140** are not required.

The fillet **140** can define at least a portion of a circle or an arcuate surface **150**, such that an effective radius **158** is defined between the fillet **140** and a center point **156** of the arcuate surface **150**. The fillet **140** comprises a thickness extending between the corner **138**, shown in dashed line, and the arcuate surface **150**. The fillet **140** is shaped such that the effective radius **158** is at least 1.5 times larger than the greater of the first or second thickness **152**, **154**. Alternatively, the shape and size of the fillet **140** can adapted to increase the length of the film holes **132**. Increasing the length L of the film holes **132** increases the value for the L/D ratio for the film holes **132**. Furthermore, the angle **128** (FIG. **5**A) defined by the corner **138** can provide for an increased or decreased effective radius **158**. For example, the filleted corner **138**, as illustrated, is a right angle providing for an effective radius **158** of approximately 2.0-2.5 times the larger of the thicknesses **152**, **154**. In alternative corners **138** where the angle **128** is acute or obtuse, for example, the fillet **140** can define an effective radius, which can be greater or smaller than the exemplary embodiment shown. As such, the fillet **140** can define an effective radius of 1.5 to 10.0 times the thicknesses **152**, **154**, or more. It should be understood, however, that the thickness defined by the fillet **140** is not limited to being defined by the angle **128** of the intersecting walls **120**, **124**.

While the thicknesses **152**, **154** are shown in reference to the tip wall **120** and the suction sidewall extension **124**, it should be appreciated that the respective geometries of the tip passage **130** within the airfoil **78** as shown is exemplary and should not limit the airfoil **78** to the geometries, dimensions, proportions, or positions as shown. The fillet **140** can be defined in additional places at the tip **80** of the airfoil **78** and will be fully described in the examples shown in FIGS. **7-10**.

It should be further appreciated that the circle shape defined by the fillet **140** is exemplary. The fillet **140** need not be shaped such that fillet **140** defines the circle shape. The fillet **140** can be any arcuate shape or segment thereof, such that a radius or local radius can define the effective radius **158**. The fillet **140** can be a non-circular arc, such that a segment of the arc or at least a portion of the fillet **140** can define a local radius to comprise the effective radius **158**. Alternatively, the fillet **140** could be defined as a compound fillet with a compound radius of curvature, having discrete arcuate or linear surfaces defining the fillet **140**. When utilizing a compound radius of curvature defined by the fillet **140**, the average overall radius could be used to determine the effective radius **158**. Further still, the fillets **140** accommodate film hole inlet or exit shaping, as well as non-linear geometries. As such, exit shaping should be understood as any shape other than a standard round inlet or exit.

Turning now to FIGS. **7**A-**9**B, multiple examples for implementation of a fillet **140** near the tip **80** are shown. In FIGS. **7**A-**7**C, the fillet **140** can be disposed within the tip passage **130** of the airfoil, illustrating the cross-section VII of FIG. **4**. Looking at FIG. **7**A, showing a prior art blade tip, the corners **138** can be defined internal of the airfoil **78**, adjacent to the tip wall **120** and the pressure and suction sidewalls **98**, **100**. In FIG. **7**B, the fillet **140** is disposed adjacent to the pressure sidewall **98**, providing for an increased length for the film hole **132**, such that the L/D ratio defined by the film hole **132** can be increased. FIG. **7**C shows an additional exemplary embodiment having a fillet **140** adjacent to both the pressure and suction sidewalls **98**, **100**. Thus, it should be understood that the fillet can be disposed adjacent to the pressure sidewall **98**, the suction sidewall **100**, or both.

Turning now to FIGS. **8**A-**8**C, the tip **80** of the airfoil can be defined by section VIII of FIG. **4**, having film holes **132** extending from the tip passage **130** to the pressure sidewall **98** of the airfoil **78**. In FIG. **8**A illustrating a prior art blade tip, similar to FIG. **7**A, the corners **138** are defined adjacent to the tip wall **120** and the pressure and suction sidewalls **98**, **100**. The film hole **132** extends through the pressure sidewall **98** providing fluid communication between the tip passage **130** and the side of the airfoil **78**.

In FIG. **8**B, the corner **138** adjacent to the pressure sidewall **98** comprises the fillet **140**, providing for an increased L/D ratio for the film hole **132** extending to the external surface of the pressure sidewall **98**. In FIG. **8**C, another example illustrates the potential to have both a film hole **132** disposed on the pressure and suction sidewalls **98**, **100**. Thus, it should be understood that the film hole **132** can be disposed through the fillet **140** to either the pressure sidewall **98**, the suction sidewall **100**, or both.

Turning now to FIGS. **9**A-**9**C, another example illustrates fillets **140** being disposed within a serpentine section of an internal cooling circuit. Looking at FIG. **9**A, showing a prior art turn **170** of a cooling circuit as the tip passage, the corners **138** can be defined at the junction between the tip wall **120** and one or more internal ribs **172**, extending along the radial, span-wise length of the airfoil **78**. Turning to FIGS. **9**B and **9**C, the fillets **140** can be placed at the corners defined against the internal ribs **172** at the tip wall **120**. The fillets **140** can be utilized to increase the length of the film holes **132** defining a greater L/D ratio for the film holes to increase film cooling effectiveness at the tip **80**.

Turning to FIGS. **10**A-**10**B, taken at the section IX of FIG. **4**, the tip **80** of the airfoil **78** with the tip shelf **126** disposed in the pressure sidewall **98**. In FIG. **10**A, similar to FIGS. **7** and **8**, the corners can be disposed within the tip passage **130** adjacent to the tip wall **120** and the pressure and suction sidewalls **98**, **100**. The film hole **132** is disposed in the tip wall **120** and extends to the tip shelf **126**. In FIG. **10**B, the corner **138** adjacent to the pressure sidewall **98** at the tip shelf **126** can comprise a fillet **140**, providing for an increased L/D ratio for the film hole **132** extending to the tip shelf **126**. Alternatively, it is contemplated that the fillet **140** can be between the tip wall **120** and the side extension **122** at the tip shelf **126**, being external of the airfoil and located within the tip channel **121**.

The film hole **132** at the tip shelf **126** can be a shaped film hole or comprise a compound film hole as described herein. The film hole **132** can be disposed on any surface of the tip shelf **126**, such as a fillet, bottom shelf surface, radial face, or any combination thereof. Additionally, the film hole **132** can have any orientation, being radial, axial, tangential, or any combination thereof. The film hole **132** can extend from the filleted surface **140** to the tip shelf **126** or from the tip wall **120** through a portion of the filleted surface **140**, being interior of or exterior of the airfoil, to the tip shelf **126**. The fillet **140** provides for an increased length for the film hole **132**, defining a greater L/D ration for the film hole **132** to improve film effectiveness.

It should be appreciated that as described herein, the filleted surfaces, being internal or external, increase the length for the film holes and the L/D values for film holes by locally increasing both the internal and external fillet radius through which the hole penetrates. The increased values for L/D provide for increased cooling film hole effectiveness. The fillets can minimally increase overall system weight without thickening an entire wall or surface. Furthermore, the fillets provide for an increase in structural support. Further still, the fillets accommodate film hole inlet or exit shaping, as well as non-linear geometries. As such, exit shaping should be understood as any shape other than a standard round inlet or exit. Additionally, as described herein, any fillets can be used in combination with one another, such that two fillets are used to increase the L/D ratio for film holes extending through the fillets.

The film holes can be in a wall surface or a fillet surface and penetrate through at least a portion of the fillet, permitting an increased length for the film hole otherwise impossible to achieve without the fillet. Furthermore, the fillets can be compounded, such as filleted internal surfaces or the combination in external and internal surfaces to further increase the length to achieve greater L/D values.

It should be further appreciated that the fillets provide for an increased length providing the potential for a wider range of film holes, such as curved film holes, "S-curved" film holes as well as other orientations beyond a standard straight or compound film hole with increased effectiveness.

It should be further understood that while the embodiments as described herein relate to an airfoil, the filleted corners can be utilized in additional engine components having intersecting walls to define a corner and utilizing film holes or cooling at or near those corners of the engine components.

This written description uses examples to disclose the invention, including the best mode, and to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and can include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

What is claimed is:

1. A blade for a gas turbine engine comprising:

an airfoil having an outer wall defining a pressure side and a suction side, the outer wall extending chord-wise from a leading edge to a trailing edge and span-wise from a root toward a tip;

a tip wall spanning the pressure side and the suction side of the outer wall and intersecting the outer wall to form at least one corner, with the outer wall having a first thickness at the corner and the tip wall having a second thickness at the corner;

a cooling passage having a portion located along the tip wall and at least partially defined by the tip wall and the outer wall;

a fillet located at the corner and having an effective radius of at least 1.5 times larger than the greater of the first and second thicknesses; and

at least one film hole extending through the fillet to fluidly couple the cooling passage to an exterior of the airfoil.

2. The blade according to claim **1** wherein the at least one film hole includes an outlet provided on at least one of the pressure side or the suction side.

3. The blade according to claim **1** wherein the tip wall at least partially defines a tip channel between extensions of the pressure side and the suction side of the outer wall, and the at least one film hole extends to the tip channel.

4. The blade of claim **3** further including a second fillet provided at a second corner defined at a junction between one extension of the pressure side or the suction side of the outer wall, with the at least one film hole extending through the second fillet.

5. The blade according to claim **1** further comprising a tip shelf disposed within the outer wall wherein the at least one film hole includes an outlet at the tip shelf.

6. The blade according to claim **5** further comprising a third fillet located at the tip shelf, with the at least one film hole passing through the third fillet.

7. The blade according to claim **1** wherein the corner extends chord-wise along the tip wall, the fillet extends chord-wise along the corner, and the at least one film hole comprises multiple film holes.

8. The blade according to claim **7** wherein the fillet is continuous.

9. The blade according to claim **7** wherein the fillet is discontinuous.

10. The blade according to claim **1** wherein the effective radius is at least 2.0 times larger than the greater of the first and second thicknesses.

11. The blade according to claim **1** wherein the effective radius is at least 4.0 times larger than the greater of the first and second thicknesses.

12. The blade according to claim **11** wherein the effective radius is less than 10.0 times larger than the greatest of the first and second thicknesses.

13. The blade according to claim **1** wherein the cooling passage has one to three corners.

14. The blade according to claim **1** wherein the cooling passage has one to two corners.

15. The blade according to claim **1** wherein the cooling passage has a symmetrical cross section.

16. The blade according to claim **1** wherein the cooling passage has an asymmetrical cross section.

17. The blade according to claim **1** wherein the film hole is linear.

18. The blade according to claim **1** wherein the film hole is non-linear.

19. The blade according to claim **1** wherein the film hole defines a centerline forming a compound angle.

20. The blade according to claim **19** wherein the compound angle comprises both a span-wise component and a chord-wise component.

21. The blade according to claim **20** wherein the film hole is non-linear.

22. The blade according to claim **21** wherein the film hole is curvilinear.

23. A method of forming a film hole in a blade of a gas turbine engine comprising forming the film hole through a fillet formed at a corner formed by an intersection of a tip wall and an outer wall, with the fillet provided in an interior of the blade and with the film hole having an outlet provided on the tip wall; wherein an effective radius of the fillet is at least 1.5 times larger than the greater of a thickness of the tip wall or a thickness of the outer wall.

24. The method of claim **23** wherein the effective radius of the fillet is greater than 2.0 times the thickness of the greater of the thickness of the tip wall or the thickness of the outer wall.

25. The method of claim **24** wherein the effective radius is at least 4.0 times larger than the greater of the thicknesses thickness among the thickness of the tip wall or the thickness of the outer wall.

26. The method of claim **24** wherein the effective radius is less than 10.0 times the thickness of the greater thickness among the thickness of the tip wall and the thickness of the outer wall.

27. A blade for a gas turbine engine comprising:

an airfoil having an outer wall defining an interior separate from an exterior, and including a pressure side and a suction side, the outer wall extending chord-wise from a leading edge to a trailing edge and span-wise from a root toward a tip;

a tip wall spanning the pressure side and the suction side of the outer wall and intersecting the outer wall to form a first interior corner at the intersection of the tip wall and the pressure side and a second interior corner at the intersection of the tip wall and the suction side;

a cooling passage at least partially defining the interior;

a first fillet located at one of the first interior corner or the second interior corner;

a first film hole extending through the first fillet;

a second fillet located at the other of the first interior corner or the second interior corner; and

a second film hole extending through the second fillet;

wherein at least one of the first film hole or the second film hole extends through the tip wall; and

wherein the first fillet and the second fillet each include an effective radius of at least 1.5 times larger than the greater of a thickness of the tip wall or a thickness of the outer wall.

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